

**Controlling Coyote Predation on Sheep in California:  
A Model Strategy**

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## **ABSTRACT**

Over a three-year period, we conducted field trials in order to develop a more effective and selective strategy for reducing coyote predation on sheep and lambs at the UC Hopland Research and Extension Center. Our primary tool for selectively removing sheep-killing coyotes was the Livestock Protection Collar (LPC), a device designed to deliver a lethal dose of toxicant to any coyote that attacks a collared sheep and punctures the device. Additionally, we used llamas as guard animals in certain pastures in an effort to deter coyote attacks.

We successfully reduced total confirmed lamb losses to coyote predation in the first two years of our study, primarily by our successful use of the LPC. Results from the third year suggest lamb loss to coyotes was higher, but the passage of Proposition 4 in November 1998 banned sodium fluoroacetate (Compound 1080), the registered active ingredient used in the LPC, leaving us without a tool for removing coyotes during a critical 4-month period.

Overall, we did not find guard llamas to be consistently effective in protecting young lambs from coyote attack. However, our findings suggest that in some situations, specifically in smaller and more open pastures, llamas may be more likely to deter coyote or dog predation. To the extent that this occurs, the llamas may be useful tools in directing predation toward target flocks of sheep equipped with LPCs.

To assist our research planning and the educational outreach efforts of our project, we established a Predator Research Advisory Committee that was composed of persons representing diverse interests and viewpoints. This Committee provided valuable input, and it also assisted our efforts in conveying our findings to our target audiences.

## EXECUTIVE SUMMARY

During a three lambing seasons (1997 through 1999), we used Livestock Protection Collars as well as guard llamas in an attempt to reduce coyote predation on sheep at the Hopland Research & Extension Center. During this time, we essentially ceased all other forms of lethal coyote control on Center property. In lambing season 1997 following the first full use of LPCs, our lamb losses were lower than they had been at any time since the early 1970s. Confirmed lamb losses to coyotes were similarly low in 1998, but the number of "missing" lambs increased substantially. We believe a large number of these "missing" lambs died of exposure because of the unusually cold and wet El Nino weather conditions during that period. In 1999, as a result of a voter-passed initiative, we were unable to use LPCs during the most critical 4-month period. Lamb losses during winter and spring 1999 approached or exceeded the high levels recorded in prior years when the Center conducted no coyote damage control efforts.

We found the LPC to be a useful and effective tool in reducing coyote predation on lambs, when used to replace other methods of lethal coyote control, during the first two years of its use at this Center. Interpretation of its effectiveness, or lack thereof, in the third year is difficult because the passage of Proposition 4 interrupted this experiment during a critical time period.

An estimate of the cost-effectiveness of LPC use can be made, based on our labor data and materials costs. If collar use can reduce lamb loss from 15.8% of the flock (our mean total loss for years 1993 through 1996) to 7% of the flock and it is assumed this is applied to a flock size of 1,000 lambs, then 88 lambs would be saved. With these assumptions, and assuming the added cost of raising "saved" lambs is minimal, a market value of \$51.50 per lamb (or approximately \$ 0.57 per pound, live weight for a 90-lb lamb) represents the break-even cost for using LPCs in a situation such as ours.

Our data do not demonstrate that guard llamas were consistently effective in protecting young lambs from coyote attack. However, it must be noted our situation challenges the effectiveness of any guard animal: pastures are large and of rugged topography, with considerable vegetation; sheep tend to spread out over sizeable areas; and predators are numerous. Based on our personal experience, we believe certain individual llamas can be somewhat effective in preventing or reducing sheep and lamb loss to coyotes and/or dogs. To the extent that this occurs, the llamas may be useful tools in attempting to direct predation toward unprotected target flocks of sheep equipped with LPCs.

Our field research advanced the development of an IPM strategy for controlling coyote depredation on sheep. Our strategy of selectively removing only sheep-killing coyotes using the LPC, coupled with use of guard llamas to assist in targeting predation on collared sheep, has less impact on local coyote populations than traditional tools used in operational coyote damage control programs. However, the future implementation of this strategy in California will be dependent upon development of an alternative active ingredient that can be used in the toxic collar device, or the development of an alternative tool that is similarly selective in removing individual, offending coyotes from a population.

Because of the sensitivity and volatility of the subject of predator damage control, we have benefited from establishing a Predator Research Advisory Committee that was composed of persons representing diverse interests and viewpoints while in support of our research efforts. This Committee provided valuable input, and it also assisted our efforts in conveying our findings to our target audiences.

## INTRODUCTION

In total U.S. sheep production, California as a state follows only Texas and Wyoming. However, coyote depredation has been an important contributing factor to the decline of the sheep industry throughout the West, and specifically in north coastal California, over the past several decades. For example, in Humboldt County, sheep have declined from 143,300 head in 1951 to 18,500 head in 1988 (Hackett 1990). Even with depressed sheep numbers statewide, California producers reported losing 5,750 adult sheep (value: \$488,750) and 16,925 lambs (value: \$600,075) for a total value of over \$1.1 million lost to coyotes during 1994. During this same year, California producers reported having spent an average of \$3.50 per breeding head on predator control efforts, mostly on non-lethal control measures (NASS 1995). A voluntary survey of Mendocino County ranchers initiated in June 1996 recorded the loss of 420 head of sheep due to predators in a 12-month period (Harper 1997).

Traditional methods for controlling coyote damage have included coyote removal by means of toxic baits (before 1972), trapping, snaring, hunting and shooting, sodium cyanide ejector devices ("M-44s"), removing coyote pups from dens, and where feasible, aerial hunting. Producers have also employed non-lethal methods to control depredation, including traditional and electric fencing, penning livestock at night, keeping lambs and other vulnerable animals near areas of human activity, and recently, the use of guard animals such as dogs and llamas. Prior to the 1972 Federal ban on toxicant use, eradication of coyotes and other predators often was the objective. Since that time, pesticide and wildlife regulations have necessitated alternative approaches, which have focused primarily on more selective removal of predators at times and locations when predation occurs (USDA 1994). Yet, despite the best efforts of producers and the cooperative USDA Animal Damage Control (now "Wildlife Services") program, losses of sheep to coyotes have often been unacceptably high (Coolahan 1990, Larson and Salmon 1988).

It has also been generally recognized, though poorly documented, that ranchers kill some coyotes illegally, landowners, and others by use of toxicants not registered for this purpose; for example, see Allen et al. (1996). A recent survey revealed that 35% of ranchers were unaware that the use of pesticides in baits to control coyotes and other predators was illegal (FMC Corp. 1995). A subsequent educational effort, sponsored and conducted on behalf of FMC Corporation, was effective in reducing illegal use of toxicants to kill predators (Jacoby et al. 1995).

The Hopland Research and Extension Center, the UC's principal rangeland sheep research facility since the early 1950s, has documented an increasing predation problem over time, primarily due to coyotes (Scrivner et al. 1985, Timm 1990). The research flock at this Center is the largest remaining sheep flock in Mendocino County, and is maintained only because its value as a research flock overrides the economic constraints that affect the area's commercial sheep flocks. High levels of coyote predation at the Center were the impetus for establishment in 1992 of a predator research effort by the USDA-APHIS-National Wildlife Research Center (NWRC), in cooperation with UC Berkeley. Intensive efforts to live-capture, radio-collar, release, and track coyotes on the Center's 5,358 acres since 1993 revealed that most of the predation appeared to be caused by a relatively few coyotes that typically were breeding territorial adults (Sacks et al. 1995). We now hypothesize that some coyotes, while spending much time in the proximity of sheep, do not kill livestock, but instead rely on alternative food resources. Traditional approaches to predator damage control typically do not differentiate between problem individuals and others within the coyote population.

Results of field investigations at Hopland during the early 1990s suggested that to be effective, coyote removal efforts must focus on those specific individuals involved in killing livestock, which are thought to be primarily breeding territorial adults. Information gained from field studies at Hopland in recent years suggests that traditional predator capture techniques such as traps, snares, and M-44 devices are at times ineffective in removing resident, territorial coyotes (Sacks et al. 1999).

**The Livestock Protection Collar:** A new, selective strategy for removing individual coyotes that attack sheep was federally registered in 1985 following a decade of research (Moore 1985). The Livestock Protection Collar (LPC) delivers a toxicant to coyotes that attack sheep or goats at the throat. This is the normal focus of coyote attack on large lambs, kids, nannies, and ewes (Connolly et al. 1976). The LPC, containing a 1% solution of Compound 1080 (sodium fluoroacetate), was first registered for use in California by USDA-Wildlife Services personnel in February 1996, and its operational use began early in 1997. The collar was previously registered and used, both by ranchers and professional animal damage control personnel, in several other states beginning in 1988 (Connolly 1993, Walton 1991, Wade 1985). Compound 1080 possesses the characteristics that make it the safest and most efficacious toxicant for collar use (Hygnstrom et al. 1994). Compared to other methods of coyote removal, the LPC is demonstrably selective for depredating individuals and can take some coyotes that seem to elude other control techniques. The safety and selectivity of the 1080-LPC has been extensively documented (Connolly 1980; Burns et al. 1991; USDA 1994).

Each LPC contains only 30 ml of sodium fluoroacetate solution containing 10 mg active ingredient per ml. Field experience in other states has shown that 11-15% of all collars put on livestock are punctured or lost (Connolly 1993); thus, the total amount of toxicant released into the environment from this use is extremely small in comparison to many other pesticides. Further, the inherent design of the collar and the way in which it is used results in the taking of only livestock-killing coyotes, a use pattern that is uniquely selective for target predators. Further, there is no evidence to suggest that resident, territorial breeding adult coyotes will avoid being killed by LPCs. Success of the Livestock Protection Collar is dependent upon good livestock management, effectively focusing coyote predation on a small, targeted group of collared sheep or goats.

Connolly (1980) recommended that LPCs be evaluated as the primary means of coyote removal, and that they be tested over a period of several years to determine if continued, selective elimination of livestock-killing coyotes would reduce the incidence of predation over time. He also noted the need to test a strategy of placing collared target animals into vacant pastures for a time period before uncollared livestock were brought into those locations, in an attempt to prevent subsequent predation.

**Guard Llamas:** The use of guard animals has in recent years become increasingly popular as a possible means of reducing coyote predation on sheep (Green 1990). While most guard animal research to date has focused on guard dogs, some individuals have suggested that llamas may be effective guard animals (Botkin and Taylor 1985, Markham et al. 1993). It was our intention to build on existing knowledge of the utility of guarding animals, specifically llamas (Franklin and Powell 1994, and recent guard llama studies being conducted by Utah State University), as well as our own previous experience with guard dogs (Timm and Schmidt 1990). We wanted to test the idea that guarding llamas may deter coyotes from attacking lambs, particularly during the 2 to 3-month period when most lambs are highly vulnerable to coyote attack but are too small to be equipped with LPCs. Further, we suspected that the presence of a llama in a non-collared flock of sheep might serve to direct predation toward "target" collared flocks in other pastures nearby.

Implementation and adoption of a successful IPM strategy to deal with coyote predation could help revitalize the sheep industry in the North Coast or other parts of California, allowing significant areas of rangeland which are now idle to be once again be used for livestock production. Sheep, managed correctly, are an environmentally friendly and sustainable agricultural enterprise, efficiently utilizing available forage to produce both food and fiber. There also exists in Northern and Southern California strong interest in the use of goats at biological tools for brush control; the main impediment to their use is predation.

**Objectives:** The specific, original objectives of this project upon its initiation in April 1996 were as follows:

- 1) Implement a novel, Integrated Pest Management (IPM) strategy for reducing coyote depredation on sheep at the UC Hopland Research and Extension Center, with emphasis on effective use of the Livestock Protection Collar, and the ancillary use of guarding animals (llamas) to assist in targeting coyote attack on collared sheep.
- 2) Encourage and facilitate, particularly within Mendocino and Sonoma counties, an innovator group of sheep and goat producers to use and/or adapt the IPM strategy, as appropriate for their own situations and in consultation with Cooperative Extension advisors and USDA-APHIS-Wildlife Services personnel, in order to reduce predation on their own flocks.
- 3) Summarize and disseminate information on the IPM strategy developed at Hopland, as adapted and tested by producers within the innovator group, to other producers throughout California.

## **MATERIALS AND METHODS**

**Objective 1:** For more than 40 years, sheep (600-1200) breeding ewes that comprise the research flock at Hopland have been distributed among 32 fenced pastures according to animal science research needs and Center management guidelines. Coyote predation occurs throughout the Center's 5,358 acres. Sheep in pastures are monitored daily, and there is a complete accounting of all individual animals by the use of unique ear-tag numbers. HREC husbandry practices permit a detailed analysis of causes of sheep death including predation. For those sheep that are simply "missing," we are able to extrapolate from data on known causes of sheep loss in order to estimate the incidence of predator-caused death. Thus, we have a considerable history of sheep survival and loss data spanning several decades. These data serve as a basis of comparison and analysis for the current effort to create a new, more effective sheep protection strategy. Sheep loss rates during the period of this study can be compared to loss rates during the period 1988-1995.

During the early 1990s, UC Berkeley students and technicians, for live capturing, collaring, and radio tracking of coyotes at Hopland, developed by USDA-APHIS-NWRC personnel, and procedures. This technology enabled the identification of specific individual animals that are involved in killing livestock, by identifying their space use patterns and proximity to killed sheep. Geographic Information Systems (GIS) technology was used to store and interpret spatial data. Through these capture and monitoring efforts, most of the resident, adult coyotes holding territories on Center property could be identified at any given time, and the approximate dimensions of their territories were defined.

**Livestock Protection Collars:** Up to 50 LPCs (containing the active ingredient sodium fluoroacetate) was initially on hand for use as needed. LPCs were fitted on lambs or adult sheep that were then placed in pastures where coyote predation was occurring or was expected to occur. Previous work showed that most coyotes that attacked collared sheep would puncture the collar and ingest a lethal dose of the toxicant, while killing the sheep (Connolly and Burns 1990). The carcasses of radio-collared coyotes involved in such attacks could be easily recovered and the individual animals identified as killers. LPCs, as a method of predator damage control, were evaluated in terms of success in removing sheep-killing coyotes, lag time between introduction of collared sheep and solution of the predation problem, and occurrence of non-target hazards or environmental contamination.

"Proposition 4," an initiative measure submitted to California voters during the November 1998 election, contained a provision that banned the use of sodium fluoroacetate (Compound 1080) for the purpose of poisoning or attempting to poison any animal. This initiative passed and went into effect immediately, thus making subsequent use of Compound 1080 LPCs illegal. Relying on previous research that demonstrated the effectiveness of an alternative toxicant, the anticoagulant diphacinone (Connolly et al. 1978), we proceeded to formulate this material for continued research use in toxic sheep collars. The collar as a tool was unavailable to us from November 1998 through March 1999, by which time we had completed the process of obtaining and formulating a diphacinone suspension and loading it into collars.

Guard Llamas: Individual llamas were to be placed with ewes and lambs in selected pastures, where loss rates of lambs to coyotes and other causes could then be monitored for comparison to pastures where llamas were not present. Llamas would be monitored for their attentiveness to the sheep, as well as for their aggressive behavior toward canids. Further, radio-telemetry data collected by USDA and UC Berkeley researchers could be analyzed to determine if coyotes tended to avoid pastures in which llamas were present.

Objective 2: A Predator Research Advisory Committee would be established, comprised of Cooperative Extension advisors, predator research scientists, woolgrowers, other agricultural producers, members of cooperating agencies, and citizens interested in wildlife management and environmental issues. The committee would be apprised of the ongoing progress of the research, and their suggestions would be incorporated so as to make evolution of the eventual IPM strategy as useful as possible to livestock producers in the North Coast area of California, and acceptable to the concerned public. Research progress would be communicated to local woolgrowers at their regularly scheduled meetings and field days. It was anticipated that exposure of this group to ongoing research would lead some producers to become innovators, adopting aspects of our developing strategy for use on their own ranches as practical. Such practices, if they proved to be effective, were anticipated to gradually spread to other producers in the North Coast and other regions.

Objective 3: Results of our IPM strategies of predator damage control would be reported to other potential users via the annual meeting of the California Wool Growers Association, through specific workshops and field days to be held at the Hopland R & E Center, through the statewide educational efforts of UC Cooperative Extension, and through other appropriate meetings and workshops as well as through publications.

## **RESULTS**

### Objective 1:

Livestock Protection Collar Use. We deployed LPCs, whenever feasible in response to repeated coyote attacks on sheep or lambs, from October 1995 through April 1999. The one exception was the period from November 1998 until late March 1999, when, as previously noted, we had no collars available due to passage of Proposition 4, which banned use of the registered active ingredient for this purpose.

As shown in Table 1, we deployed LPCs a total of 21 times, using between 1 and 32 (typically 20-25) collared lambs or yearling sheep in each trial. During 13 of these deployments, coyotes attacked one or more collared sheep. In three deployments, coyote attacks were not successful in taking coyotes because the coyote injured or killed the sheep without puncturing the collar. However in 10 deployments, at least one collared sheep was attacked and the collar punctured. We believe our use of the LPC resulted in the death of 12 or 13 livestock-killing coyotes. During this time we used no other lethal coyote control measures, with the following exceptions: Between April and December 1996 we used radio-telemetry to determine that three coyotes were likely involved in killing sheep. These three

individuals were subsequently removed by use of firearms aided by radio-telemetry in order to identify their approximate locations. In November 1997 Center personnel shot a female coyote; this coyote was subsequently found, via DNA analysis conducted by UC Berkeley researchers, to be responsible for several sheep kills. In September 1998, a deer hunter shot a single radio-collared coyote that was implicated via radio-telemetry data in being involved in several incidents of sheep predation. In April 1999, a single non-collared coyote was shot while in the process of killing and feeding on a lamb.

For all trials, we calculate that we killed one coyote per 833 collar-nights (if 12 coyotes were killed) or one coyote per 769 collar-nights (if 13 were killed). In seven deployments conducted since January 1998, however, we achieved a success rate of one coyote killed per 454 collar-nights. While the number of deployments during 1998 and 1999 was small, we believe that our improved success rate was in part due to experience obtained from past collar use. Our success rate was similar to those documented for collar use elsewhere (Connolly 1993, Walton 1991).

Our experience in using the LPC revealed the major use limitations area) inadvisability of use in large pastures and rugged terrain, because it is difficult to locate killed sheep and missing collars, and, b) inconsistency of coyote killing patterns, resulting in predation having stopped by the time collared target sheep are deployed. To remedy the first problem, which resulted in two lost collars during our first several months of field trials, we borrowed 20 radio-transmitters for attachment to LPCs. This greatly assisted us in locating target sheep killed at remote sites. The radio-transmitters enabled our LPCs to be used in virtually any pasture at the Center. The second difficulty may be partially resolved by deploying LPC-equipped sheep promptly following the first identified coyote kill, rather than waiting until two or more kills occur in a specific pasture. More frequent collar deployments would require more time and effort in livestock management; however, if successful this would result in fewer sheep lost to coyotes.

We made four attempts to use collared sheep in a preventive mode, that is, to stimulate attacks on collared sheep in pastures where no recent predation had occurred, but where there was a known history of coyote predation. All such attempts were unsuccessful; that is, coyotes attacked none of the collared sheep.

In earlier research, the collar has been proven to pose essentially no risk to humans, nontarget wildlife, or to the environment (Connolly 1980). In our trials at Hopland, no non-target deaths were found. However, during our 21 collar deployments, we had 4 instances where collared sheep were attacked by predators other than coyotes. In three instances, sheep were attacked by mountain lions; in two cases, individual lions killed single lambs but did not puncture the collars. In the third instance, a single lion killed 11 collared sheep in one night, puncturing 9 collars and presumably ingesting a lethal dose of toxicant. In the fourth instance, a bear either attacked or scavenged a single collared sheep, but it could not be discerned if the sheep was originally killed and the collar punctured by the bear or by a coyote. Although collared sheep were never deployed with the intention of attracting predators other than coyotes, in the above incidents the attacking predators were considered to be "target" animals.

Table 2 summarizes lamb losses to coyotes and to unknown causes for years 1984 through 1999. It should be noted that in years preceding 1992, the Center practiced typical operational coyote control measures, relying on the local USDA trapper and on HREC staff to remove coyotes using traps, snares, shooting, denning, and M-44 (sodium cyanide) devices as necessary to attempt to reduce livestock losses. During 1992, a newly initiated USDA coyote research program began attempting to trap and snare coyotes for the purpose of radio-collaring and releasing animals for behavioral study. During the period March 1993 through September 1994, operational coyote control was stopped on Center property at the request of USDA researchers, as it was deemed to be interfering with their capture / radiotelemetry efforts. Operational coyote control was resumed in early October 1994 and continued until late 1995, when use of the LPC on a research basis was substituted for all other lethal coyote control methods.

Labor required to conduct the LPC deployments was recorded for each year of this project and averaged 351 person-hours per year. If valued at \$12 per hour, this totals \$4,212 in labor annually. Cost of LPC purchase was approximately \$24 per collar, and we assume that 40 collars would be needed to support this effort over a 3-year period, or an average cost of \$320 per year in materials. Thus, total costs of deploying LPCs would be approximately \$4,523 annually.

**Guard Llamas.** Five llamas were present on HREC property year-round, but our specific study period was defined as the lambing season (typically January through mid-April), when we placed 2 or 3 llamas individually into pastures containing ewes and lambs. We chose treatment (llama) pastures that were similar in topography and location to control (no llama) pastures, so that lamb losses might be legitimately compared. Most of our llamas proved relatively intractable; that is, they were extremely difficult to move routinely from one pasture to another, so our original experimental design was modified so that a single llama stayed in a given pasture for the duration of the lambing season.

Table 3 compares lamb loss data over three lambing seasons (1997-1999) in pastures where guard llamas were present or absent. In lambing season 1997, 1 lamb was confirmed killed by coyotes in the three pastures where llamas were present, while coyotes killed 6 lambs in "control" pastures without llamas. In each case, total lambs lost in pastures without llamas was higher (as a percentage of available lambs) than in pastures with llamas. However, total numbers of lambs lost in each group were similar. In the 1998 and 1999 lambing seasons, llama presence or absence did not appear to influence either confirmed coyote predation or total lamb loss in the two paired pastures observed each year. Radio-telemetry data on coyotes collected by UC Berkeley and USDA-funded students during 1997 and 1998 indicated no tendency for coyotes to avoid pastures in which llamas were present (K. Blejwas, personal communication).

In addition to these data, a number of observations about the llamas' ability, or absence of ability, to guard sheep were noted and recorded. For example, from mid-June to mid-July 1998, six yearling ewes were confirmed killed in James I pasture by coyotes in the presence of the guard llama "Hawkins" (Coyote attacks in this pasture ceased only after two coyotes punctured LPCs deployed there). Other instances of confirmed coyote kills in pastures where llamas were present are listed on Table 3. However, several observations confirmed some degree of guarding effectiveness: On June 12, 1998 a coyote was found dead in the pasture where the guard llama "Sammy" was present. Subsequent necropsy revealed the coyote appeared to have died from trauma to the torso and lungs, consistent with the type of injury that could have been caused by llama attack. Then, in late August and early September 1998, a guard llama was observed by both HREC staff and neighboring landowners to be effective in limiting damage to sheep caused by at least 3 free-ranging domestic dogs that appeared on HREC property several times over a period of 2 to 3 weeks. In one incident, the llama was observed during daylight hours to be fighting off two dogs, holding them at bay and at a distance from the flock of sheep in that pasture. Were it not for the presence of the llama, it is highly likely that many sheep would have been attacked and injured and killed.

**Objective 2:** The Predator Research Advisory Committee that was established in early 1996 at the initiation of this project met 7 times between August 1996 and February 1999. Over this time period, a total of 32 individuals participated in one or more meetings, not including HREC staff or student technicians working at Hopland. The group maintained a high level of interest in predator research being conducted at the Center, as well as related research being done at other sites. At a result of discussions held during its first meetings, the committee was expanded to include representatives of additional state and county agencies (e.g. Calif. Dept. of Fish & Game, County Agricultural Commissioners).

One of the Committee's significant contributions was a result of discussions in early 1997 about the need for new methods of delivering baits to coyotes. Following this discussion, HREC personnel wrote and submitted a proposal to further study the "Coyote Lure Operative Device, " a concept originally developed in the early 1980s (Fagre and Ebbert, 1988), to the UC Division of Agriculture & Natural Resources Competitive Grants Program. A one-time grant of \$29,660 was received and in January 1998 a graduate student from Utah State University arrived at Hopland with the goal of developing a field study of coyote behavior in relation to this device.

Objective 3: Formal presentations of our research progress and/or results were made at all 7 meetings of the Predator Research Advisory Committee. Five articles dealing with our coyote research and/or how it relates to predator management in the North Coast were written and published in the Mendocino County *Farm Bureau News* (see publications list). Three hands-on training sessions regarding use of the Livestock Protection Collar were held at HREC (fall 1995, fall 1996, and winter 1997), designed to provide USDA-APHIS-Wildlife Services personnel and ranchers with the information needed in order to use this tool operationally. Certification exams were administered to those needing to comply with this requirement prior to using LPCs. A total of more than 80 individuals received training during these sessions.

In addition, individuals involved with this project made the following presentations:

Blejwas, K., M.M. Jaeger, and D.R. McCullough. Turnover, territories, and sheep depredation in an exploited coyote population. Presented at 33rd Annual Meeting, Western Section of The Wildlife Society, Feb. 5-8, 1997, San Diego, CA.

Blejwas, K., M.M. Jaeger, and D.R. McCullough. Reducing coyote predation on livestock through selective control. Presented at 4<sup>th</sup> Annual Conference of The Wildlife Society, Sept. 21-27, 1997, Snowmass Village, CO.

Sacks, B.N., J.C.C. Neale, M. Jaeger, and D.R. McCullough. Ecology of coyotes in a sheep ranching environment. Presented at 3<sup>rd</sup> Annual Conference of The Wildlife Society, Oct. 1-5, 1996, Cincinnati, OH.

Sacks, B.N., J.C.C. Neale, M. Jaeger, and D.R. McCullough. Ecology of coyotes in relation to depredation and control on a California sheep ranch. (Poster presentation). Presented at 33rd Annual Meeting, Western Section of The Wildlife Society, Feb. 5-8, 1997, San Diego, CA.

Timm, R. M. Predator research at Hopland - an update. Presented at the Annual Convention, California Wool Growers' Assoc., Sept. 6, 1996, Sparks, NV.

Timm, R.M. Update on predator research at Hopland: toxic collars and guard animals. Presented at annual meeting of Western Coordinating Committee-95 "Vertebrate Pests of Agriculture, Forestry, and Public Lands" November 18-21, 1996, Reno, NV.

Timm, R.M. Update on predator research and management strategies. Presented to USDA-APHIS-Wildlife Services annual conference, Sept. 8-10, 1997, Quincy, CA.

Timm, R.M. Presented testimony to Assembly Committee on Parks, Water and Wildlife on coyote research and management. Nov. 30, 1998, Salinas, CA.

Timm, R.M. and J.R. Hays. Livestock protection collar use at the U.C. Hopland Research & Extension Center. Presented at annual meeting of Western Coordinating Committee-95, "Vertebrate Pests of Agriculture, Forestry and Public Lands" Nov. 17-19, 1998, Reno, NV.

Timm, R. M., G. D. Simmons, and J. R. Hays. 1997. Livestock protection collar use in California. Presented at 13th Gt. Plains Wildlife Damage Control Workshop, Apr. 16-19, Nebraska City, NE.

## DISCUSSION

Objective 1: We successfully employed the Livestock Protection Collar at the Hopland Research & Extension Center to remove sheep-killing coyotes from our property during a 3-year period. We were the most successful in using this tool during lambing seasons 1997 and 1998, and the number of coyotes taken per collar exposure-night generally increased as we gained more experience in successfully deploying collared target sheep. In previous years while relying on USDA-Wildlife Services personnel to solve predation problems by removal of coyotes using traps, snares, shooting, denning, and M-44 devices, it was common for 10-20 or more coyotes to be removed annually from Center property (Conner et al. 1998). During the 3 years when LPCs were used as our primary predator removal tool, we believe we removed only 12 or 13 coyotes with collars plus an additional 6 coyotes with firearms, for an average removal of about 6 coyotes per year. HREC staff noted an apparent increased presence of coyotes on HREC property, in terms of coyote sightings and field sign (scats and tracks). These observations paralleled our reduction in lamb and sheep losses, supporting our hypothesis that some coyotes are less prone than others to attack sheep or lambs. This may lend credence to the notion that there is positive value in having stable pairs of dominant, territory-defending coyotes present on rangelands if these coyotes are not inclined to attack sheep. However, we suspect that at some point in time, most dominant coyotes living in close proximity to livestock may begin preying on them. Therefore, a selective method (such as the LPC) needs to be available to managers to solve the predation problem by removing the offending coyotes.

We were successful in adapting the use of radio-transmitters, attached to LPCs, to allow us to find target sheep that might have been killed by coyotes in rugged terrain and otherwise would have been lost. While the cost of such radio-telemetry equipment precludes its operational use, it greatly aided our research effort, allowing us to confidently put collared target sheep into large and rugged pastures.

Successful "targeting" of predation so that sheep-killing coyotes find and kill LP-Collared sheep is the major challenge in successful use of this device. We were unsuccessful in four attempts to use LPCs in a preventive mode, that is, to stimulate attacks by placing collared sheep into a pasture where no recent predation had occurred, but where there was a known history of coyote predation.

Through use of the LPC and guard llamas, we hoped to significantly reduce the number of lambs lost to coyotes on Center property. Indeed, the number of lambs lost during the 1997 lambing season (following the first full year of LPC use) was the lowest it had been since the early 1970s. This is true whether lamb loss is expressed as total number lost or as a percentage of lambs available (see Table 2). During the 1998 lambing season, a similarly small number and percentage of lambs were confirmed as coyote-killed (1.5% of available lambs in 1997, and 1.7% of available lambs in 1998); this loss is lower than, or equal to, our lamb loss for any year since 1991. To find two consecutive years with such low coyote-confirmed losses at HREC, one has to look back to the years 1974-1975.

However, during the 1998 lambing season a substantially higher number of lambs were "missing." These are lambs whose carcasses could not be recovered in time to determine cause of death, if found at all. In most years, we believe a high percentage of these "missing" losses are due to predation.

But in 1998, an unusually high number of "missing" lambs are known to have been deaths related to sustained cold, wet weather conditions ("El Nino"). Available Center labor was insufficient to retrieve all carcasses of lambs that died because of exposure, and scavengers typically consume many such carcasses within 24 to 48 hours. However, a total of 74 lamb carcasses were retrieved, of which only 13 were confirmed to have been killed by coyotes. Fifty-one lambs (69% of those found) died of causes other than predation (primarily exposure), while the remaining 10 lamb carcasses were not found in time to determine cause of death. Thus, we are confident that the increase in "missing" lambs over the 1997 level was not caused largely by coyote predation.

During the 1999 lambing season, 117 lambs were lost, a number considerably higher than in 1997 or 1998. As in 1998, most of these lambs were in the category "missing" rather than confirmed coyote kills. Winter weather during 1999 was considerably milder than in 1998, and therefore we have no reason to suspect that an unusually high number of lambs perished from exposure. We suspect that the majority of these 100 "missing" lambs succumbed to coyote predation. As noted previously, the passage of Proposition 4 made LPCs unavailable from early November 1998 through late March 1999, the most critical time period for us to conduct coyote control. We believe our inability to selectively remove sheep-killing coyotes during this pre-lambing and early lambing period led to this higher loss rate.

A factor that possibly confounds our lamb loss data is the reduction in number of available lambs during the period 1997-1999, as compared to earlier years. Because of reduced research demand and higher animal production costs, our research sheep flock numbers began to decline after the 1995 lambing season, reaching a low of only 526 lambs on pasture during 1999 (see Table 2). Despite lower lamb numbers, our lambs were pastured in the same locations as in past years, but at lower density per acre. Thus, if dominant, territorial pairs of coyotes are responsible for most predation, the number of potential predators to which our lambs are exposed may be relatively constant over the years and the number of lambs killed may also be relatively constant regardless of the number exposed. If so, our analysis of lamb loss as a percentage of lambs available may actually have overstated the impact of coyote predation in the past three years as compared to earlier years.

Based on a labor plus materials cost of \$4,532 annually to purchase and deploy LPCs, an estimate can be made of the cost-effectiveness of this technique. If collar use can reduce lamb loss from 15.8% of the flock (our mean total loss for years 1993 through 1996) to 7% of the flock and it is assumed this is applied to a flock size of 1,000 lambs, then 88 lambs would be saved. With these assumptions, and assuming the added cost of raising "saved" lambs is minimal, a market value of \$51.50 per lamb (or approximately \$ 0.57 per pound, live weight for a 90-lb lamb) represents the break-even cost for using LPCs.

The larger number of lambs lost during the 1998 and 1999 lambing seasons allows us to take a critical look at the effect our guard llamas may have had in preventing or reducing such losses. Table 3 lists lamb losses both in total numbers and as a percentage of lambs available. In 1998, no coyote-killed lambs were found in one pasture with a llama, and total losses were low as compared to the "control" pasture. However, in the second pair of test pastures, lamb losses including coyote-killed lambs were higher with the llama than in the "control" pasture without a llama. During 1999, lamb losses appeared not to be influenced by whether a llama was present or absent in the test pastures. Thus, llamas appeared not to consistently reduce losses. These results are similar to our previous experience with livestock guard dogs on this Center (Timm and Schmidt 1990). A further consideration of these data reveals most consistent reductions in lamb loss were achieved when llamas were used in East Vassar and West Vassar pastures, both relatively small and open pastures. Our experience suggests the most important factors influencing the effectiveness of guard llamas in reducing predation are the size and the openness of a pasture. In our case, these factors may override individual behavioral differences among llamas, presuming that the llama will consistently remain in proximity to sheep or visa versa.

On the other hand, our guard llamas may have assisted us in efforts to "target" coyote predation on LPC-equipped sheep in adjacent pastures. We noted this may have been the case two instances: the 1/17/97 LPC deployment in Upper Horse pasture, when a guard llama was present in the adjacent Lambing pasture; and in the 2/18/98 LPC deployment in East Vassar pasture, when a guard llama was present in the adjacent West Vassar pasture.

Some individual llamas behave aggressively toward canids. This trait was reflected in repeated problems our herders encountered in attempting to move, handle or otherwise manage sheep with the aid of their herding dogs when llamas were present. Llama presence, in our experience, makes sheep movement and management considerably more difficult. This is a significant impediment to use of guard llamas. We believe this llama behavior has resulted in herding dog injury, as well as behavioral problems exhibited by our working dogs after exposure to llamas. In addition to its behavior toward predators, it is also likely that an individual llama's effectiveness as a guard animal will depend on the degree to which it is bonded to a group of sheep, and on its ability to see the entire pasture and the sheep present within it.

We theorize that in the right situation (a relatively small, flat, open pasture where a llama could likely see any predator that entered), a llama possessing appropriate behavioral responses to predators could be an effective deterrent to coyote predation. From our data, we cannot show that our guard llamas significantly reduced lamb losses to coyotes. The suspected increase in lamb loss in the presence of llamas during the 1999 lambing seasons leads us to wonder whether a llama's effectiveness may inevitably decrease over time if the depredating coyote is not removed. Perhaps, initially a coyote (especially a newly established breeder) might avoid killing in a pasture with a llama, but as its familiarity with the llama increases, its fear of the guard animal may decrease. Further experience will be needed to determine the optimum relationship of guard animals and selective predator removal in IPM predator management strategies.

Objective 2: The Predator Research Advisory Committee met regularly during the 3-year time span of this project, and the group gained enthusiasm for our coyote research as it matured. Its input helped project leaders, as well as UC Berkeley and USDA-sponsored students, focus efforts on those aspects of the project that would be most beneficial to livestock producers. We also believe the Committee was useful in conveying, by word-of-mouth and informally, the progress made by this research group in attempting to find practical, workable solutions to this difficult problem. Those participants who were unable to attend every meeting often contacted us and requested meeting summaries, handouts, or reports produced by the group.

Discussions initiated by the group regarding the need for additional coyote control tools led to successful funding by UC of a project to conduct further field studies on the Coyote Lure Operative Device (CLOD).

The adoption of the strategy we developed, namely the use of LPCs as a primary means of coyote damage control, would in practice be hampered by the numerous use restrictions that must be followed as conditions of its registered use. LPC use by USDA-APHIS-Wildlife Services personnel as an additional tool to aid in controlling predation began in 1997 but ceased in November 1998, when the registered active ingredient (sodium fluoroacetate) was banned by the passage of Proposition 4. Future LPC use in California will depend upon reversal of Proposition 4 or upon registration of an alternative active ingredient, neither of which appears to be likely to occur within the next several years.

Objective 3:

Six formal presentations concerning coyote research at Hopland were made by project personnel, or by students closely associated with this work during the 3-year span of this project. Additionally, a dozen written publications have been produced, and it is likely that several more presentations and publications based on this project's work will be completed in 1999 or 2000. In this way, information on our goals, results, and the need for continued study have been communicated to livestock producers, the

public, wildlife managers and other agency personnel, and to wildlife biologists. While, because of Proposition 4, our work on the LPC appears at the present time to have been in vain, it remains of considerable interest to livestock producers and wildlife damage management specialists outside of California. However, if the CLOD can be further developed as a relatively selective device for removing sheep-killing coyotes, then the principles of coyote management developed here can continue to be put to use. Without a selective removal method, livestock producers will be forced to continue relying on older methods of wholesale coyote removal.

## **SUMMARY AND CONCLUSIONS**

During a three-year period, we used Livestock Protection Collars as well as guard llamas in an attempt to reduce coyote predation on sheep at the Hopland Research & Extension Center. During this time, we essentially ceased all other forms of lethal coyote control on Center property. In lambing season 1997 following the first full use of LPC, our lamb losses were lower than they had been at any time since the early 1970s. Confirmed lamb losses to coyotes were similarly low in 1998, but the number of “missing” lambs increased substantially. We believe a large number of these “missing” lambs died of exposure because of the unusually cold and wet El Nino weather conditions during that period. In 1999, as a result of a voter-passed initiative, we were unable to use LPCs during the most critical 4-month period. Lamb losses during winter and spring 1999 approached or exceeded the high levels recorded in prior years when the Center conducted no coyote damage control efforts.

We found the LPC to be a useful and effective tool in reducing coyote predation on lambs, when used to replace other methods of lethal coyote control, during the first two years of its use at this Center. Interpretation of its effectiveness, or lack thereof, in the third year is difficult because the passage of Proposition 4 interrupted this experiment during a critical time period.

Our data do not demonstrate that guard llamas were consistently effective in protecting young lambs from coyote attack. However, it must be noted our situation challenges the effectiveness of any guard animal: pastures are large and of rugged topography, with considerable vegetation; sheep tend to spread out over sizeable areas; and predators are numerous. Based on our personal experience, we believe certain individual llamas can be somewhat effective in preventing or reducing sheep and lamb loss to coyotes and/or dogs. To the extent that this occurs, the llamas may be useful tools in attempting to direct predation toward unprotected target flocks of sheep equipped with LPCs.

Our field research advanced the development of an IPM strategy for controlling coyote depredation on sheep. Our strategy of selectively removing only sheep-killing coyotes using the LPC, coupled with use of guard llamas to assist in targeting predation on collared sheep, has less impact on local coyote populations than traditional tools used in operational coyote damage control programs. However, the future implementation of this strategy in California will be dependent upon development of an alternative active ingredient that can be used in the toxic collar device, or the development of an alternative tool that is similarly selective in removing individual, offending coyotes from a population.

Because of the sensitivity and volatility of the subject of predator damage control, we have benefited from establishing a Predator Research Advisory Committee that was composed of persons representing diverse interests and viewpoints while support of our research efforts. This Committee provided valuable input, and it also assisted our efforts in conveying our findings to our target audiences.

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## **APPENDICES**

Table 1: Livestock Protection Collar Deployments

Table 2: Coyote-Killed and Missing Lambs

Table 3: Lamb Loss in Presence / Absence of Guard Llamas

**Table 1**

**Livestock Protection Collar Deployments**  
**Hopland R & E Center**

<i>deployment #</i>	<i>date</i>	<i># sheep collared</i>	<i>pasture</i>	<i>collar-nights exposed</i>
[1]	10/3/95	25	Middle	966**
[2]	11/14/95	23	James III	462
[3]	2/28/96	23	Middle	380
[4]	3/19/96	22	South	609*
[5]	7/6/96	23	Lower Strip	374
[6]	7/31/96	21	West Vassar	441
[7]	9/17/96	21	Lambing, Upper Horse	540
[8]	10/14/96	20	Lower HQ West	20
[9]	1/17/97	12	Upper Horse	352* <sup>+</sup>
[10]	2/3/97	18	West Vassar	270
[11]	2/10/97	10	James III	252
[12]	3/6/97	20	Neiderost	361*
[13]	7/31/97	20	Middle	682
[14]	9/29/97	30	Huntley	1560*
[15]	1/8/98	32	Watershed I	640
[16]	2/18/98	25	East Vassar	469*
[17]	3/26/98	31	Huntley	372
[18]	6/2/98	25	Lower HQ West	564*
[19]	6/25/98	15	James I	261**
[20]	7/31/98	1	Lambing / Huntley	33*
[21] <sup>#</sup>	3/12/99	17	Lower Strip	<u>385*</u>

*total exposure:*     9939 collar-nights

\* one collar punctured; one coyote presumed killed

\*\* two collars punctured; two coyotes presumed killed

<sup>+</sup> mate of coyote that punctured collars subsequently found dead

<sup>#</sup> LP Collars containing active ingredient diphacinone

***Summary***

Coyotes removed: 12 (*or 13*)

***Success Rate***

One coyote removed per 833 (*or 769*) collar-nights

**Coyote-Killed and Missing Lambs**  
 UC Hopland Res. & Ext. Center

**Table 2**

<i>lambing</i> <i>season</i>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>	<u>1990</u>	<u>1991</u>	<u>1992</u>	<u>1993</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>	<u>1999</u>
<b>lambs avail.</b>	1225	1266	1647	1641	1482	1532	1174	1317	1102	1312	1438	1207	1089	756	759	526
<b>coyote-killed</b>	39	37	49	67	36	52	9	31	19	36	84	54	43	11	13	17
as %	3.2%	2.9%	3.0%	4.1%	2.4%	3.4%	0.8%	2.4%	1.7%	2.7%	5.8%	4.5%	3.9%	1.5%	1.7%	3.2%
<b>missing</b>	108	53	67	105	122	199	93	62	125	98	190	136	157	23	79	100
as %	8.8%	4.2%	4.1%	6.4%	8.2%	13.0%	7.9%	4.7%	11.3%	7.5%	13.2%	11.3%	14.4%	3.0%	10.4%	19.0%
<b>total:</b>	147	90	116	172	158	251	102	93	144	134	274	190	200	34	92	117
<b>% lost:</b>	12.0%	7.1%	7.0%	10.5%	10.7%	16.4%	8.7%	7.1%	13.1%	10.2%	19.1%	15.7%	18.4%	4.5%	12.1%	22.2%

**Lamb Loss in Presence / Absence of Guard Llamas****Table 3**

UC Hopland Res. &amp; Ext. Center

**Winter/ Spring 1997**

Llama: Pasture	<u>present</u> E. Vassar	<u>absent</u> W. Vassar	<u>present</u> Lambing	<u>absent</u> Upper Horse	<u>present</u> WS II	<u>absent</u> WS I
Lambs available	39	20	74	53	110	99
Killed by coyote	0	1	0	2	1	3
Dead, cause unknown	1	1	2	0	2	2
Missing, cause unknown	1	0	2	2	3	4
Total lambs lost	2	2	4	4	6	9
% Killed by coyote	0.0%	5.0%	0.0%	3.8%	0.9%	3.0%
% Dead, cause unknown	2.6%	5.0%	2.7%	0.0%	1.8%	2.0%
% Missing, cause unknown	2.6%	0.0%	2.7%	3.8%	2.7%	4.0%
% Total lambs lost	5.1%	10.0%	5.4%	7.5%	5.5%	9.1%

**Winter / Spring 1998**

Llama: Pasture	<u>present</u> W. Vassar	<u>absent</u> E. Vassar	<u>present</u> Upper Horse	<u>absent</u> Lambing
Lambs available	33	29	67	72
Killed by coyote	0	3	5	3
Dead, cause unknown	0	3	6	4
Missing, cause unknown	2	0	4	1
Total lambs lost	2	6	15	8
% Killed by coyote	0.0%	10.3%	7.5%	4.2%
% Dead, cause unknown	0.0%	10.3%	9.0%	5.6%
% Missing, cause unknown	6.1%	0.0%	6.0%	1.4%
% Total lambs lost	6.1%	20.7%	22.4%	11.1%

**Winter / Spring 1999**

Llama: Pasture	<u>present</u> Buck	<u>absent</u> Lower Strip	<u>present</u> WS II	<u>absent</u> WS I
Lambs available	31	24	90	74
Killed by coyote	1	4	2	1
Dead, cause unknown	2	1	4	1
Missing, cause unknown	5	0	10	13
Total lambs lost	8	5	16	15
% Killed by coyote	3.2%	16.7%	2.2%	1.4%
% Dead, cause unknown	6.5%	4.2%	4.4%	1.4%
% Missing, cause unknown	16.1%	0.0%	11.1%	17.6%
% Total lambs lost	25.8%	20.8%	17.8%	20.3%